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FLUCTUATIONS IN THE VALUES OF THE SOLAR CONSTANT

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In February, 1923, Dr. C. G. Abbot wrote (*1*) "Arrangements have been made to continue daily observations at both stations (Harqua Hala and Montezuma) until July, 1925, when it will be earnestly considered whether they should continue longer, and if so, under what auspices." This was understood here to mean that Doctor Abbot intended by the date mentioned to summarize and criticize his ingenious and almost superhuman undertaking for the continuous observation of the solar constant, and no attempt was therefore made to touch publicly upon a remarkable point in connection with Table 8, which was published at the same time by Abbot (loc. cit., pp. 78–81), and the relationship with a certain natural occurrence shortly to be mentioned. The report on the matter was merely passed on to the president of the International Radiation Commission, Professor Maurer, with a letter dated April 15, 1924, requesting him to retain it for the time being with the documents. Doctor Abbot has now published the criticism referred to (*2*), and it is most valuably supplemented by the detailed criticism, which accords with the importance of the subject, of Doctor Marvin, Doctor Kimball, and Mr. Clough. (*3*). In all these criticisms the important point, which to me appears a very striking one, was not referred to, and I take leave, therefore, in the present remarks to draw attention to it.

Reference has, indeed, been made here and there in the literature to a great volcanic eruption which took place in the middle of December, 1921, in the Chilean-Argentine Andes (in the Astronomische Nachrichten, No. 5279, the site of the volcano is given as λ 72°, ϕ 40°), but it would seem that the great importance of the occurrence has perhaps not been fully realized. In January, 1922, I happened to see a detailed description from the pen of a young Davoser engaged on a farm near Huapi on the Lago Nahuel (λ 71°, ϕ 41°). His report on the occurrences of December 15, 1921, was to the following effect:

> A terrific storm, with dreadful flashes of first yellow, then red, then green lightning, and a severe earthquake were followed at midday by a great darkness and a rain of snow-white ashes that began to fall on December 15 and was still falling on December 17—the date of writing the letter. Abundant quantities of pumice also fell at Huapi, and the lake and rivers were quite covered with it. At Puerto Manzano, his former residence, the ashes lay 8 to 10 inches deep, and all the cattle and the vegetation were doomed to destruction.

I submitted to analysis specimens of the ashes which he sent; they were identified as pumice. There can be no doubt that this was an important natural occurrence, far exceeding the outbursts otherwise frequent in that volcanic region; and Professor Wolf, of Heidelberg, in the Astronomische Nachrichten, loc. cit., brought the following observations into relationship with it:

La Plata, December 17, 1921 (dust clouds).
German Southwest-Africa, December 27, 1921 (nocturnal striæ).
Sonneberg, January 25, 1922 (nocturnal striæ).
Heidelberg, January 30, 1922 (nocturnal striæ).
Essen, February 3, 1922 (nocturnal striæ).

At Davos after January 21, 1922, small decreases of the radiation intensity and other optical phenomena (e. g., strong zodiacal light, comparatively strong purple light, etc.) pointed in the same direction; and one could adduce the unusual halo phenomena (*4*) observed at Ellendale, N. Dak., and New Haven, Conn., on February 12 and 25, 1922; also the two sharp peaks which are separated by a deep trough in Schmid's (Oberhelfenswil, Switzerland) curve of the circumpolar radiance (*5*) which stand out prominently from the gradual fall associated with the secular course (the trough is strongly reminiscent of that found by J. Maurer and myself on the occasion of the Katmai eruption (*6*)); furthermore, the heavy dust showers (*7*) observed in the North Atlantic Ocean from May 12 to 22, 1922; also the luminous night clouds seen at Danzig in June, 1922 (*8*). The dust clouds had evidently crossed the Equator and had reached extensive regions of the Northern Hemisphere. That they had here been productive of effects for a considerable time was not at all astonishing to the writer, for in both his extensive researches, Himmelshelligkeit, Himmelspolarisation und Sonnenintensität, 1911–1918 (*9*) and Dämmerungs- und Ringerscheinungen, 1911–1917 (*10*) and situated at a distance of about a third of the earth's circumference, he had for nearly two years, until May, 1914, been able to follow systematically the gradual decline of the Katmai eruption by a series of precise and reciprocally controlling observations of the polarization, the distribution of celestial brightness, and the intensity of the transmitted radiation in different parts of the spectrum It may be remarked that the outburst of the Katmai Volcano is the only one not occurring in the period of greater solar activity—and whose effects were therefore not masked by those ascribable to secular variations—which has hitherto been exactly studied. And in connection with the observations referred to above, I may mention that since the same period I find the sky at Davos not nearly so sharply differentiated; the isophotes are no longer so distinctly recognizable by their different blue shades; the inner and outer disks of the solar corona are not so distinct; also, that since that time the twilight phenomena have largely diminished as regards magnificence of color.

Doctor Abbot's stations at Montezuma and Harqua Hala will probably also have been reached by these dust clouds, which seems to agree with Table 8 (loc. cit), according to which during the 6 days which followed

the volcanic eruption no observations whatever are recorded at either station, and during the next 11 days two observations only. Was the weather during just those 2½ weeks so almost unchangeably bad in both these favored regions of the world *independently of the volcanic outbreak?* If, however, any relationship exists between this absence of observations and the volcanic eruption, would it not seem probable that a large part of the considerable fall of the solar constant, which Doctor Abbot has found to have occurred precisely since that time (*11*), was feigned by the fine ashes floating in the higher regions? The secular course, however, will also, perhaps, account for a certain proportion.

After the outburst of the Katmai Volcano in 1912, be it remembered, the effect of which was rendered strongly manifest at Mount Wilson, as is, for instance, to be seen from Fowle's calculations of the dust content (*12*) (1912), 25 per cent; in June, 1913, still 2.6 per cent, against only one-half of 1 per cent in (1910–11) the quite irregular, partly very high, but also partly very low, values of the solar constant of 1912, which are now rejected in the criticisms, were followed in 1913 by a considerable sag (interrupted here and there by unusually high, narrow peaks) which led far below the minimum anticipated for the secular course for 1914–15. Professor Marvin has already drawn attention in his criticism (loc. cit., p. 286) to these "spurious variations of the solar constant as the consequence of a violent eruption."

It is sufficiently clear that a registration requiring at least seven minutes to perform, and with nonhomogeneous dust masses expelled with differing force at different times and unequally dispersed by unequal winds, will show different absorption capacity for different wave lengths; but even were the radiation to be reckoned with only that arising from the solar disk alone and traversing only the equal-dimensioned atmospheric section lying between the sun and the observer, unequal effects upon the "fundamental" quantity are to be assumed, as Professor Marvin stresses with gratifying clearness. viz, the quantity which is indicated by the pyrheliometer. But with the standard pyrheliometer, and still much less with the secondary instruments, it is not by any means the sun alone and the small part of the sky in front of it which radiates into the instruments, but a much larger part, which differs in all instruments and is often very unequally demarcated.

According to Figures 4 and 8 in volume 3, pages 53 and 64, of the Annals of the Smithsonian Astrophysical Institution, there radiates into the standard instruments ("water flow" and "water stir") in addition to the sun a circular celestial zone extending to 3° 48′ and 6° 10′ from the sun's edge; while in Marvin's pyrheliometer, according to the figure contained in the MONTHLY WEATHER REVIEW, 1919, page 769, this zone extends to about 4° 26′. With the silver disk, and similarly with Ångström's and Michelson's instrument, unequally demarcated celestial zones are effective besides the sun. which differ according to the side and altitude, and amount to a mean of 5° from the sun's edge. This radiation from the sky is by no means negligible. In the Abhandlungen d. Preuss. Meteorolog. Inst., volume 6, pages 38–44 and pages 52–54, I have investigated in different parts of the spectrum (photo-metrically and photo-electrically) the distribution of brightness and the absolute brightness of the sky in immediate proximity to the sun, above, laterally, and below, and at different solar altitudes, supporting my conclusions with numerous data and curves. On page 61 the conclusion has been reached to the effect that on the average a measuring instrument with angular aperture 7° (celestial zone of 3° 15′ from the sun's edge radiating with the sun) causes the solar brightness to appear by 1½ per cent too high, and a measuring instrument with angular aperture 20° (with radiating celestial zone 9° 45′ from the sun's edge) by even 3 per cent at a mean solar altitude; at a lower altitude of the sun the error is essentially greater. And these errors hold good for the clear, high-Alpine Davos sky; near large lowland towns, as derived from measurements undertaken at Kiel, the errors must be estimated at three or four times greater. For the total radiation such precise measurements of the decrease of brightness from sun to sky are not yet available; the errors will certainly be considerably less, but scarcely so small, even in favored situations, as to be always inappreciable by comparison with the fractional percentages to which the limits of error in measuring methods have been reduced by Doctor Abbot. When volcanic dust is floating above the sites of observation these errors will be very considerably increased, and in a different manner at different times and for different solar altitudes.

In the determination of the solar constant the pyranometer endeavors, indeed, within certain limits to overcome this deficiency. According to the MONTHLY WEATHER REVIEW, 1921, pages 651–652, the celestial area radiating upon this instrument was different in amount at different times, beginning with 19° around the sun; later less. This method is probably insufficiently precise and would perhaps be more adequately substituted by the method employed at Davos for determining the decrease of brightness from sun to sky. The latter has been recommended, besides loc. cit., in the Astr. Nachrichten, volume 209, No. 4999, August, 1919, as suitable for determining the momentarily prevailing extinction coefficient.

From the viewpoint indicated I think the pyrheliometric instruments are still capable of improvement. Instruments possessing a different angular aperture can not exhibit equal correlation factors for different solar altitudes and under different atmospheric conditions, and I think this appears to find expression in all the published comparison series, not merely of the standard instruments with each other, but also of these with the secondary instruments. I called attention to this circumstance at the meetings of the International Radiation Commission held at Davos from August 31 to September 2, 1925. The difficulty can only be avoided—and I speak from the experience of many years' construction work—by regulating with precision the direction of the solar radiation by means of the best quartz lenses in order to reduce the area of sky around the sun as much as is consistent with precise adjustment. In this respect the Davos pyrheliograph (*13*) is, so far as I am aware, the only hitherto exact, physically perfected instrument. In single measurements the amount of sky which it allows to radiate upon the sensitive thermopile is limited to within 8.4 minutes of arc from the sun's edge; for continuous registrations 47.8 minutes of arc have been allowed in order to take into account slight irregularities of the clockwork mechanism due to the considerable temperature variations in the sun and shade (e. g., from passing clouds) such as occur in the high Alpine regions. The lens also affords protection from the influence of wind and dust. If the lens is kept clean the reflection and absorption capacity are always the same.

Will it ever become possible to measure the fluctuations of the solar constant with such accuracy as Doctor

Abbot at present believes, even after having successfully eliminated all the instrumental and observational errors, as well as the influence of the variation of permeability of the terrestrial atmosphere so far as it is due to the daily and annual progress of the meteorological elements in the lower layers? From the constitution of the sun we may draw the conclusion that the radiation which it emits is subject to enormous fluctuation at every moment. Certainly the corona rays are to be rightly regarded, at least in part, as an indication of the directions in which a special abundance of cathode rays are emitted from the sun, giving rise to condensation products along their path. The sun spots allow rays to radiate directly from the photosphere quite unfiltered by the solar atmosphere, whose absorption in the long-waved ultra-violet still measurable in the earth's atmosphere amounts to approximately 52 per cent. Between sun spots, however (which must extend to at least 700 km. to become visible even in the best telescopes), and completely closed solar atmosphere, all possible transitions are to be assumed, and consequently continual variations at every single point of the sun's atmosphere. It is only a question, I think, whether it can be shown beyond question that the ever-present considerable and lively variation of the emission of rays extends to the spectral regions that are allowed to pass through the earth's atmosphere. And here the real difficulty commences. This permeability of the earth's atmosphere is in all probability very largely influenced by variations in intensity of the incident radiation, and in the sense that it decreases when the emitted solar radiation increases in intensity, because a greater incident radiation brings about greater condensations and chemical transformations in the earth's atmosphere. The simplest expression of the condensations which take place is in the extent and the brightness of the "telluric solar corona," otherwise termed the "circumpolar radiance" (circumpolarer Schein), as described in the Meteorologische Zeitschrift, 1923, page 349, by J. Maurer, following F. Schmid's observations, and as I have continuously followed (Ringerscheinungen um die Sonne, 1911–1917) (*14*) in all its subdivisions (aureole, ring, inner and outer disk) by measurement at Davos. In Table 76 (loc. cit.) are assembled day for day the data which show with scarcely an exception that in the years 1915–1917 increase in the relative number of sun spots was accompanied by increase of the ring phenomena (telluric solar corona) and diminution of the radiation intensities. There it is demonstrated that the effects make their appearance suddenly and rapidly decline, and that they are at their greatest with newly appearing sun spots or with those which suddenly undergo a great increase in size. In this work, moreover, an endeavor is made to demonstrate that, and to what extent, the differentiated light phenomena of the telluric solar corona are due to diffraction effects in exceedingly minute ice crystals (Uebercirren = supercirri) which themselves owe their origin to condensation nuclei emitted from the sun. It is further emphasized that at different situations on the earth these condensation nuclei fall in different degrees of intensity, and already at that date (February, 1917) the conclusion was deduced therefrom (p. 91) viz: "It is perhaps only possible to determine accurately the fluctuations of the solar constant when measurements are undertaken at several places (including if possible the antipodes) and when due consideration is taken of the degree of purity of the earth's atmosphere, which is apparently often variable with place and time."

But variations in the short-waved ultra-violet and cathode radiation of the sun must be effective to a still greater degree in the higher layers, where ozone arises from oxygen through their influence, than in the comparatively low atmospheric layers in which the telluric solar corona has its origin. A more profitable method, therefore, of recording the variation of the solar constant than the infinitely troublesome method employed by Doctor Abbot would perhaps be to undertake measurements in parts of the spectrum in which ozone absorbs characteristically. Such investigations should, however, be performed at the altitude of high mountains, not, as by Fabry and Buisson (*15*) with their extremely delicate but unfortunately also very intricate method, in the midst of the smoke of a large port. They will also require to be greatly simplified, should it be desired—as will presumably be necessary in the near future—to collect a great deal of material in a short time. Doctor Abbot has directed his attention to the infra-red line 10.4 μ of ozone (*16*), as had already been suggested by K. Ångström. In view of the great sensitiveness of the photo-electric cells the prospect would appear to me to be favorable if measurements were made in the analyzed light of the extreme ultra-violet. The *quartz* cells with cadmium layer brought out by me some months ago seem to possess sufficiently constant sensitiveness.

With reference to H. H. Clayton's weather forecasts (*17*), these appear to me to show, with greater certainty the more they are fulfilled, that Doctor Abbot does not measure the absolute fluctuations of the solar constant, but with them their effect upon the terrestrial atmosphere also, and particularly their effect in producing changes of its permeability. It is to be hoped that the great reward which is Doctor Abbot's due for his superhuman performances will in future lie in the preeminent importance of these predictions.

A short remark, in conclusion, remains to be made on the suitability of site of the Chilean station at Montezuma for determinations of the solar constant. Doctor Abbot was in Calama until December 14, 1921, i. e., a day prior to the great volcanic outburst, yet during the long return journey across the South American Continent he apparently heard nothing of the tremendous natural occurrence. Is this not a sign of the frequency with which volcanic eruptions occur in the South American States, and is such a country adapted for an observatory for the measurement of the solar constant?

LITERATURE CITED.

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(*2*) Smiths. Misc. Coll., 77: no. 5, June 20, 1925.
(3) Mo. Wea. Rev., 1925, July and August.
(*4*) Mo. Wea. Rev., 1922, 50:131–133.
(*5*) Met. Zeit., 1923, 349.
(*6*) Met. Zeit., 1914, 49.
(*7*) Mo. Wea. Rev., 1922, 50:301.
(*8*) Das Wetter, 1925, 62.
(*9*) Abhandl. d. Preuss. Met. Inst., 6.
(*10*) Abhandl. d. Preuss. Met. Inst., 5: no. 5.
(*11*) Mo. Wea. Rev., 1923, 51: Figure on 0. 76.
(*12*) Smiths. Misc. Coll., 1918, no. 3.
(*13*) Met. Zeit., 1922, 304.
(*14*) Abhandl. d. Preuss. Met. Inst., 5: no. 5.
(*15*) Astrophys. Jour., 54: Dec., 1921.
(*16*) Smiths. Misc. Coll., 74: no. 7, 1923, 22.
(*17*) Smiths. Misc. Coll., 77: no. 6, 1925.